Model for Calculating the Quantity of Water Lost by Evaporation during Oven Drying of Clay

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Abstract
Model for calculating the quantity of water lost by evaporation during oven drying of clay has been derived. The model; $\gamma = \exp[(\ln t)^{1.0638} - 2.9206]$ indicates that the quantity of evaporated water during the drying process is dependent on the drying time, the evaporating surface being constant. It was found that the validity of the model is rooted on the expression $(\text{Log}\beta + \ln\gamma)^N = \ln t$ where both sides of the expression are correspondingly almost equal. The respective deviation of the model-predicted quantity of evaporated water from the corresponding experimental value is less than 37% which is quite within the acceptable deviation range of experimental results, hence depicting the usefulness of the model. [Researcher. 2009;1(3):8-13]. (ISSN: 1553-9865).

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1. Introduction

Studies [1] have shown that the contents of the basic clay materials are divided into three groups. The first group involves clays containing mainly the mineral kaolinite. The second groups are clays containing mineral rnontmorillorite, while the third group are clays which are intermediate product of disintegration of mica into kaolin. Unal [2] reported that the structure of sinters and pellets may be divided into two parts viz, the mineral and the pores. He stated that the properties of pellets and sinters are closely related to the mineral constituents.

Furnass [3] reported that voids volume in packed dispersed powder depend on the ratio of smallest size (Ss) to largest size (Ls) particle as well as the percentage of constituent monosized particles. He maintained that the smaller the (Ss/Ls) ratio, the more continuous the distribution and the lower the void volume of the system. Singer and Singer [4] found that on heating dried clays, water is given off. With time, a hard but porous piece forms. A swollen appearance might occur during the release of some gases, but overall shrinkage must occur when verifications set in leading to a strong dense piece.

Nwoye [5] reported that chemical composition of the pellet, pelletisation parameters and firing conditions affect the shrinkage of clay pellets. He posited that the rate of chemical reaction is very much dependent on the gas-solid contact area, which is mostly governed by the porosity of the pellet. He stated that shrinkage of clay is probably due to volume change resulting from evacuation of water from the voids, reduction of the size of the pores as well as decrease in the interparticle separation.

It has been reported [6] that fine particles shrink more, are denser and exhibit excellent mechanical properties. Studies [6] carried out to investigate the relationship between particle size and size distribution with linear drying shrinkage, firing shrinkage and apparent porosity shows that no visible relationship exists between particle size and linear drying shrinkage. In this work [6], finer particles were found tend to shrink more. They concluded that the finer the particle size, the lesser the apparent porosity and greater the bulk density.

The behaviour of ceramic products has been found [7] to be very dependent on their composition, grain size, grain distribution, structure of grain and pores. Nwoye [8] also posited that the grain size and grain distribution of the clays have significant effect on their physical and technological properties (binding ability, shrinkage and plasticity).

It has been reported [9] that pores are deleterious to the strength of ceramics not only because they reduce cross-sectioned area over which the load is applied but more importantly act as stress concentrators.

Pore deformation mechanism in shrinking Nigeria clays, was studied [10] over a range of heating temperature from 1000 to 1300^0C. The results of the study indicate that pores pre-existing before sintering deformed by the collapsing of the wall surrounding the pores. It was discovered [10] that the wall surrounding the pre-existing pores collapsed as a result of the weakening of the clay-binder contact surface and loosening of the macro structure of the formed clays, occasioned by the response of the clay and binder to temperature increase. It was also found [10] that binder burn-out which releases

gases,elimination of gaseous product of decomposition and oxidation of some clay constituents as well as evaporation of free water between clay and binder particles, all played very vital roles in decreasing the pre-existing interparticle separation hence deforming the pores.

Nwoye [11] studied the effect of porosity on the shrinkage behavior of clay pellets and briquettes of different porosities. The result of the investigation indicates that shrinkage which is a major cause of rupture in fired clay increased with decrease in porosity. It was also discovered [11] that the porosity of pellet/briquette plays important role in controlling and determining the shrinkage index of the pellet.

Reed [12] described firing as having three stages through which it proceeds; preliminary reactions which include binder burnout, elimination of gaseous product of decomposition and oxidation, sintering as well as cooling which may include thermal and chemical annealing.

Several works [1, 6, 12, 13] have been carried out on shrinkage of clay during drying. In all these works, porosity has been shown to influence the swelling and shrinkage behaviour of clay products of different geometry. It has been reported [12] that drying occurs in three stages; increasing rate, constant and decreasing rate. He pointed out that during the increasing rate; evaporation rate is higher than evaporating surface hence more water is lost. At constant rate, the evaporation rate and evaporation surface are constant. He posited that shrinkage occurs at this stage. Keey [13] also in a similar study suggested that at this stage, free water is removed between the particles and the interparticle separation decreases, resulting in shrinkage. During the decreasing rate, particles make contacts as water is removed, which causes shrinkage to cease.

Model for calculating the volume shrinkage resulting from the initial air-drying of wet clay has been derived [14]. The model calculates the volume shrinkage when the value of dried shrinkage experienced during air-drying of wet clays is known. The model was found to be third-order polynomial in nature. Olokoro clay was found to have the highest shrinkage during the air drying condition, followed by Ukpor clay while Otamiri clay has the lowest shrinkage. Volume shrinkage was discovered to increase with increase in dried shrinkage until maximum volume shrinkage was reached, hence a direct relationship.

The present work is to derive a model for calculating the quantity of water lost by evaporation during oven drying of Olokoro (Nigeria) clay at 90^0C.

2. Model formulation

Experimental data obtained from research work [15] carried out at SynchroWell Research Laboratory, Enugu were used for this work. Results of the experiment used for the model formulation are as shown in Table1.Computational analysis of the experimental data [15] shown in Table 1, gave rise to Table 2 which indicate that;

$$(\text{Log } \beta + \ln\gamma)^N = \ln t \quad \text{(approximately)} \quad (1)$$

Multiplying the indices of both sides of equation (1) by 1/N

$$\text{Log } \beta + \ln\gamma = (\ln t)^{1/N} \quad (2)$$

Introducing the value of N into equation (2)

$$\text{Log } \beta + \ln\gamma = (\ln t)^{1/0.94} \quad (3)$$
$$\text{Log } \beta + \ln\gamma = (\ln t)^{1.0638} \quad (4)$$
$$\ln\gamma = (\ln t)^{1.0638} - \text{Log } \beta \quad (5)$$
$$\gamma = \exp[(\ln t)^{1.0638} - \text{Log } \beta] \quad (6)$$

Introducing the value of β into equation (6) reduces it to;

$$\gamma = \exp[(\ln t)^{1.0638} - 2.9206] \quad (7)$$

Where

(γ) = Weight of water lost by evaporation during the drying process (g)

(β) = Area of evaporating surface (mm^2)

N = 0.94; (Collapsibility coefficient of binder-clay particle boundary at the drying temperature of 90^0C) determined in the experiment [15].

(τ) = Drying time (mins.).

Table 1: Variation of quantity of evaporated water with drying time.[15]

(t)	(β)	(γ)
30	833	2.50
50	833	4.40
70	833	5.60
90	833	6.60
110	833	7.70
130	833	8.60
	50	
	50	
	50	**Table 1: Variation of concentration of dissolved iron with weight input of iron oxide ore and final solution pH. (Nwoye;2006)**
	50	

Table 2: Variation of lnt with $(\text{Log}\beta + \text{ln}\gamma)^N$

lnt	Logβ	lnγ	$(\text{Log}\beta + \text{ln}\gamma)^N$
3.4012	2.9206	0.9163	3.5395
3.9120	2.9206	1.4816	4.0276
4.2485	2.9206	1.7228	4.2347
4.4998	2.9206	1.8871	4.3754
4.7005	2.9206	2.0412	4.5071
4.8675	2.9206	2.1518	4.6015

3. Boundary and Initial Conditions

Consider a rectangular shaped clay product of length 49mm, width 17mm, and breadth 9mm exposed to drying in the furnace while it was in wet condition. Initially, atmospheric levels of oxygen are assumed. Atmospheric pressure was assumed to be acting on the clay samples during the drying process (since the furnace is not air-tight). The grain size of clay particles used is 425µm, weight of clay and binder (bentonite) used (for each rectangular product); 100g and 10g respectively, quantity of water used for mixing; 2% (of total weight), drying temperature used; 90^0C, area of evaporating surface;833mm^2 and range of drying time used; (30-130 mins.).

The boundary conditions are: atmospheric levels of oxygen at the top and bottom of the clay samples since they are dried under the atmospheric condition. No external force due to compression or tension was applied to the drying clays. The sides of the particles and the rectangular shaped clay products are taken to be symmetries.

4. Model Validation

The formulated model was validated by direct analysis and comparison of the model-predicted µ values and those from the experiment for equality or near equality.

Analysis and comparison between these γ values reveal deviations of model-predicted γ from those of the experimental values. This is believed to be due to the fact that the surface properties of the clay and the physiochemical interactions between the clay and binder, which were found to have played vital role during the evaporation process [15] were not considered during the model formulation. This necessitated the introduction of correction factor, to bring the model-predicted γ value to that of the corresponding experimental value (Table 3).

Deviation (Dv) (%) of model-predicted γ values from the experimental γ values is given by

$$Dv = \frac{Pw - Ew}{Ew} \times 100 \qquad (8)$$

Where   Pw = Quantity of water evaporated as predicted by model (g)

Ew = Quantity of water evaporated as obtained from experiment (g) [15]

Correction factor (Cf) is the negative of the deviation i.e

$$Cf = -Dv \qquad (9)$$

Therefore

$$Cf = -100 \left(\frac{Pw - Ew}{Ew} \right) \qquad (10)$$

Introduction of the value of Cf from equation (10) into the model gives exactly the corresponding experimental value of γ [15].

5. Results and Discussion

The derived model is equation (7). A comparison of the values of γ obtained from the experiment and those from the model shows little deviations, hence depicting the reliability and validity of the model (Table 3).The respective deviation of the model-predicted quantity of evaporated water from the corresponding experimental value is less than 37% which is quite within the acceptable deviation range of experimental results, hence depicting the usefulness of the model. It was found that the validity of the model is rooted in equation (1) where both sides of the equation are correspondingly almost equal. Table 2 also agrees with equation (1) following the values of $(Log\beta + ln\gamma)^N$ and lnt evaluated from Table 1 as a result of corresponding computational analysis.

Table 3: Comparison between quantities of evaporated water as predicted by model and as obtained from experiment [15]

γ_{exp}	γ_M	Dv (%)	Cf (%)
2.50	2.1316	-14.74	+14.74
4.40	3.8464	-12.58	+12.58
5.60	5.6897	+1.60	-1.60
6.60	7.6323	+15.64	-15.64
7.70	9.6571	+25.42	-25.42
8.60	11.7526	+36.66	-36.66

Where

γ_{exp} = Weight of water evaporated as obtained from experiment [15]
γ_M = Weight of water evaporated as predicted by the derived model

6. Conclusion

The model calculates the quantity of water lost by evaporation during oven drying of Olokoro (Nigeria) clay at 90^0C. It was found that the validity of the model is rooted in equation (1) where both sides of the equation are correspondingly almost equal. The respective deviation of the model-predicted quantity of evaporated water from the corresponding experimental value is less than 37% which is quite within the acceptable deviation range of experimental results.

Further works should incorporate more process parameters into the model with the aim of reducing the deviations of the model-predicted γ values from those of the experimental.

Acknowledgement

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